KN-16 Ultrafast dynamics in condensed matter

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This lecture will give an introduction to the field of ultrafast x-ray diffraction (UXRD) and related techniques such as inelastic or diffuse x-ray scattering. Generally, we excite molecules or solids by ultrashort light pulses and monitor the dynamics on the natural timescale of atomic motion, i.e with a resolution of about 100 femtoseconds. The idea is to generate movies that teach us how energy flows in complex material systems. The main body of the lecture will discuss very recent experimental progress in the field using both laser-based plasma x-ray sources and synchrotron radiation. As a tutorial example, we demonstrate how UXRD can monitor the inhomogeneous excitation of metallic thin films and the associated generation of hyper-sound waves. This process is used to tailor giant phonon-wavepackets with a well defined wavevector, although localized to few tens of nanometers. We not only observe the generation and decay of these phonons directly by UXRD. We can even monitor nonlinear phonon-phonon interaction in real time. As a second very recent research area monitors the structural changes of rare earth metals after heating with ultrashort laser pulses. The transient lattice strain can be used as a local ultrafast thermometer, that tells us about the heat flow within a multilayered sample, where a very large fraction of the heat can be trapped in antiferromagnetic excitations (magnons and fluctuations). We discuss the complex lattice dynamics induced by various stress contributions from anharmonic lattice heat expansion to forces induced by the magnetic exchange interaction. In the vicinity of the Neel temperature we observe critical behavior in the observed relaxation timescales that are connected with fluctuations at the phase transition.

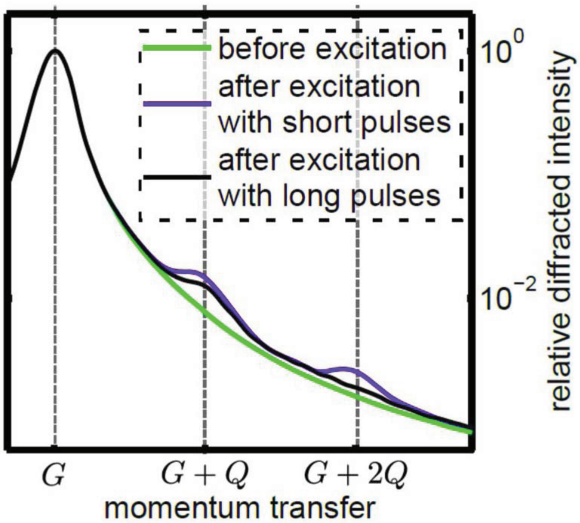

Figure 1. Experimental data showing the Bragg peak of a single crystal (green) and how it changes when a phonon with wavevector q (black) is written into the crystal. When the second harmonic at 2q is present as well, it can be monitored at the respective momentum transfer.

Keywords: Ultrafast X-ray Diffraction, Inelastic Scattering, Phonons, anharmonic, nonlinear, femtosecond, antiferromagnet, ferromagnet, exchange interaction,heat transport, magnons, fluctuations